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**Inventor:**

Douglas Spriggs Selsam  
2600 Porter Ave. Unit B  
Fullerton, CA 92833

## Side-Furling Co-Axial Multi-Rotor Wind Turbine

By Douglas Spriggs Selsam

(This patent application is a continuation in part of U.S. Patent Application Serial Number 09/997,499 (Filing Date November 23, 2001) expected to issue as U.S. Patent #6,692,230, which is itself a continuation in part of U.S. Patent application number 09/881,511 filing date June 14, 2001 issued as U.S. Patent Number 6,616,402, and contains by reference all that is contained therein. That is to say that the present application incorporates by reference all that is included in U.S. Patent Application number 09/997,499 and U.S. Patent Application number 09/881,511, the entireties of which are expressly incorporated by reference herein and made a part of this specification.)

### **BACKGROUND:**

This invention relates to wind turbines.

### **Prior Art:**

In many embodiments of this previous application 09/997,499 protection from overspeed in excessively strong winds was accomplished by aligning the entire driveshaft parallel to the wind direction, reducing the offset angle  $\alpha$  of the driveshaft to the wind direction to zero, so that all rotors become located within the wake of upwind rotors, except the first rotor. This method works well for overspeed protection in a normal storm where wind speeds may reach around 45 or even 50 miles per hour. The power of the

wind is, however, a function of the wind speed cubed. In hurricane force winds, in the range of 60, 70 mph and higher, the upwind rotor alone, when aimed directly into the wind, may therefore still produce enough power to burn out the generator or otherwise damage the turbine. In such terrifically strong winds the downwind rotors, even within the wake of upwind rotors, may also produce enough power to contribute to damage from overspeed.

The passive sideways furling method of overspeed protection is common on small wind turbines. The turbine is mounted at a slight offset distance horizontally to one side from the azimuthal (yaw) pivot point. This makes the turbine susceptible to being blown downwind of this azimuthal pivot point in strong winds, thereby placing it sideways to the wind, so that the rotor does not face into the wind, and therefore the rotor produces reduced power, or no power at all, depending on how much it is turned away from the wind direction. Maximum protection is achieved when the rotor is oriented so that it is aimed approximately 90 degrees from the wind direction, or completely sideways. During normal operation a tail forces the turbine to remain aimed into the wind. The tail projects from the frame of the turbine by a pivot that is at an angle from vertical, with gravity acting to keep the tail fairly perpendicular to the plane of the rotor, since the weight of the tail is at its lowest point when extending perpendicular to the plane of the rotor. In strong winds however, the thrust force pushing the turbine downwind is strong enough to overcome the weight of the tail; the tail remains pointed downwind, but is lifted up by the turbine yawing downwind of its azimuthal pivot point, since the pivot it is mounted on is at an angle from vertical. A means other than gravity, such as a spring, may also be used to hold the tail perpendicular to the rotor during normal operation, as is commonly known in the prior art.

Because their blades are located so close to the tower, upwind single rotor horizontal axis turbines are known to suffer from tower strikes in strong winds, when the blades are bent back by the wind and hit the tower. If guy wires are used to stabilize the tower, they must be attached to the tower at a point below the lowest reach of the blades to avoid being struck by the blades. This fact that the blades of conventional single-rotor horizontal axis turbines are located so close to the azimuthal (yaw) pivot point also normally precludes mounting with directional freedom on a tripod type tower having a

wide stance, or mounting on other wide structures such as buildings. A conventional wind turbine cannot simply be hung off the edge of a building, since to respond to wind from all directions, it must be able to rotate (yaw) to face the wind. Therefore if a conventional turbine is mounted atop a building, it needs an additional tower to elevate the turbine above the building so that the blade tips are above the level of the roof, to avoid having the blades strike the roof of the building.

## **BRIEF SUMMARY OF THE INVENTION:**

The present invention, a co-axial, multi-rotor wind turbine, incorporates passive sideways furling as a means for overspeed protection, similar to the sideways furling common on small, single-rotor turbines. As with single-rotor turbines, the multi-rotor turbine is mounted at a slight horizontally offset distance from the azimuthal (yaw) pivot point. This makes the turbine susceptible to being blown downwind of this azimuthal pivot point in strong winds, thereby placing it sideways to the wind, so that the rotors do not face into the wind, and thereby produce reduced power, or no power at all, depending on how much they are turned away from the wind direction. Maximum protection is achieved when the rotors are oriented so that they are aimed approximately 90 degrees from the wind direction, or completely sideways. During normal operation a tail forces the turbine to remain aimed almost directly into the wind, but at an offset angle  $\alpha$ , to allow fresh wind to each rotor. The tail projects from the frame of the turbine by a pivot that is at an angle  $\beta$  from vertical, with gravity acting to keep the tail at an angle  $\gamma$  from the driveshaft, since the weight of the tail is at its lowest point within the allowed range of travel of the tail when extending at angle  $\gamma$  to the direction of the driveshaft. The angle  $\gamma$  is similar to, although not necessarily exactly the same as, angle  $\alpha$ , the direction that the driveshaft is offset from the wind direction. The tail at angle  $\gamma$  is properly oriented to maintain the frame of the turbine at such an orientation that the driveshaft is caused to remain at angle  $\alpha$  from the wind direction. A means other than gravity, such as a spring, may also be used to hold the tail at angle  $\gamma$  from the driveshaft during normal operation.

Since the rotors of the co-axial, multi-rotor wind turbine of the present invention are placed at spaced intervals along the driveshaft, they may be placed at some distance from

the azimuthal (yaw) pivot point. This distance allows clearance from a tripod tower, or other wide mount, such as a building. If guy wires are used to stabilize a conventional tower the guy wires may be attached at any height on the tower without danger of blade strikes.

## **BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING:**

**Fig. 1** Shows an oblique side view of a passively aimed wind turbine installation of the first embodiment, in its normal operating position, at an angle  $\alpha$  from the wind direction, having a tail that pivots from a tail pivot, a tail stop that sets the detent offset angle  $\gamma$  of the tail from the direction of the driveshaft, and offset extension means 95, which holds the driveshaft at a horizontal distance from yaw bearing 35.

**Fig. 2** Shows the turbine of the first embodiment in the furled position for protection from overspeed. The turbine has been blown downwind of the yaw bearing, and is oriented across the wind, so that power is reduced. The tail is still aimed downwind but is now nearly perpendicular to the driveshaft.

**Fig. 3** Shows a side view of the turbine and tail in the normal operating position, and shows the angle  $\beta$  of the tail pivot from vertical, with the tail resting in its detent position.

**Fig. 4** Shows a side view of the turbine and tail in the sideways furling position, for protection from overspeed in excessively strong winds.

**Fig. 5** Shows an oblique side view of the second embodiment, in its normal operating position, wherein the tail pivot is vertical, therefore the tail is level, and the tail is maintained in its position by a resilient means, such as a spring, instead of by gravity. The turbine is mounted atop a tower stabilized by guy wires which reach up higher on the tower than the lowest point swept by the blades, made possible due to the inherently ample clearance of the rotors from the tower of this design.

**Fig. 6** Shows a side view of the second embodiment, showing the level tail extending from a vertical tail pivot, and the tower stabilized by guy wires which reach up higher on the tower than the lowest point swept by the blades, made possible due to the inherently ample clearance of the rotors from the tower of this design.

**Fig. 7** Shows an oblique side view of a wind turbine installation of the third embodiment, with the turbine mounted directly atop a tripod tower having a wide stance, made possible due to the inherently ample clearance of the rotors from the tower of this design.

**Fig. 8** Shows an oblique side view of a passively aimed wind turbine installation of the fourth embodiment, with the turbine mounted directly atop a building, made possible due to the inherently ample clearance of the rotors from the central pivot of this design.

### **Part Numbers in the Drawing Figures:**

- 4** bearing support means
- 5** cantilevered bearing means
- 6** load
- 10** elongate driveshaft
- 11** bearing
- 13** horizontal axis type rotor
- 15** axle
- 27** resilient spring means
- 34** damping means (shock absorber)
- 35** horizontally rotatable azimuthal directional orientation means (yaw bearing)
- 36** elevation angle control means
- 37** lifting mechanism
- 38** pivot means
- 49** upwind section of the driveshaft
- 50** downwind section of the driveshaft
- 67** ballast counterweight means
- 90** tower means
- 91** outer rotating half of load 6
- 92** inner rotating half of load 6 (turns in opposite direction of 91)

- 93 supporting armature means
  - 94 fluid reactive offset angle inducing means
  - 95 downwind offset extension means
  - 96 active azimuthal directional orientation control means
  - 97 streamlined mounting pylon
  - 98 streamlined nacelle
  - 120 tail pivot
  - 122 tail
  - 124 tail stop
  - 126 resilient means to hold tail in detent position angle gamma (tail spring)
- 
- A horizontal distance that the driveshaft projects upwind
  - B horizontal distance that the driveshaft projects downwind if different from A
  - $\alpha$  offset angle of driveshaft from wind direction
  - $\beta$  offset angle of tail pivot from vertical
  - $\gamma$  offset angle of tail from driveshaft in horizontal plane

## **DETAILED DESCRIPTION OF THE INVENTION:**

### **1. First Embodiment: Figs. 1 - 4**

Fig. 1 shows a side-furling, horizontal-axis, co-axial multi-rotor wind turbine having a total of 4 rotors, 2 upwind and 2 downwind with the turbine in its normal operating position. A driveshaft 10 projects upwind and downwind from cantilevered bearing means 5, which comprises a bearing support means 4 and two bearings 11, with bearing support means 4 comprising an elongate structure that supports a bearing 11 toward each end. Near the center of the bearing support means is a load 6, driven by the upwind section 49 and the downwind section 50 of the driveshaft 10. The driveshaft is held with rotational freedom by the bearings.

The cantilevered bearing means 5 with its projecting driveshaft 10 is supported by offset extension means 95, which holds the driveshaft at a horizontal distance from yaw bearing 35. This configuration alone, without the action of a tail, will result in the driveshaft being blown downwind of the yaw bearing, so that the driveshaft 10 with its attached

rotors 13 becomes oriented perpendicular to the wind. In such a configuration the rotors, being co-axial with the driveshaft, are also perpendicular to the wind direction, and therefore produce little or no power. This configuration then, is ideal for protection from overspeed, and is illustrated in Figs. 2 and 4.

A tail 122 is attached to the cantilevered bearing means by tail pivot means 120. Tail pivot means 120 is tilted back generally toward the downwind section 50 at an offset angle  $\beta$  from vertical as shown in Fig. 3. Due to gravity then, the tail is inclined to pivot toward the downwind section 50, but is stopped in its downward swing by a tail stop 124 which holds the tail at a detent angle  $\gamma$ . Angle  $\gamma$  is the offset angle of tail from driveshaft in horizontal plane in the normal operating position. This angle  $\gamma$  is similar to, but not necessarily exactly the same as, offset angle  $\alpha$  which is the offset angle of driveshaft from wind direction. The action of the wind on the tail projecting at angle  $\gamma$  is sufficient to cause a rotational (yawing) force that acts to keep the turbine headed into the wind at offset angle  $\alpha$  which is the offset angle of driveshaft from wind direction. Offset angle  $\alpha$ , combined with the distance between rotors, allows fresh wind to reach each rotor, by placing downwind rotors largely out of the wake of upwind rotors. So in the illustration shown, the natural tendency of the turbine as a whole to be blown downwind of the yaw bearing and therefore to rotate (yaw) about the yaw bearing in a counterclockwise direction when viewed from above, so as to become aligned across the wind, is balanced by the clockwise push from the tail, which acts through inclined tail pivot 120 to rotate the turbine clockwise. The balance of these two forces results in the turbine being held at offset angle  $\alpha$  from the wind direction, and at this angle  $\alpha$  from the wind direction, maximum power is achieved. Note that as is known in the art, resilient means such as a spring may be used in lieu of gravity to maintain the tail in position at angle  $\gamma$  during normal operation, and to allow the turbine to furl to the side at excessively high wind speeds.

At higher wind speeds, where it becomes desirable to protect the turbine from overspeed, the clockwise rotational force of the tail as directed against inclined tail pivot 120 is insufficient to overcome the natural tendency of the turbine to be blown downwind of the yaw bearing. At this wind speed the turbine is blown downwind of the yaw bearing, becoming oriented across the wind, reducing the power produced by the rotors, thereby



protecting the turbine from overspeed. The speed at which this begins to take place can be adjusted by adjusting the length of the tail, the area of the tail, the offset angle  $\beta$  from vertical of the tail pivot, the distance that offset extension means 95 places the driveshaft from the yaw bearing, and the weight of the tail. For instance a heavier tail will cause the turbine to remain aimed into the wind at angle  $\alpha$  at higher speeds, so that protection from overspeed, or sideways furling, takes place at a higher windspeed. Increasing the distance that offset extension means 95 places the driveshaft from the yaw bearing will tend to make it easier for the turbine to be blown downwind from the yaw bearing, lowering the wind speed at which sideways furling takes place. This type of configuration and behavior is generally known in the prior art of single-rotor small wind turbines, except that in the prior art the detent position for normal operation is for the tail to be blown perpendicular to the plane of the rotor, and for the driveshaft and rotor to therefore be aimed straight forward into the wind, whereas in the present invention, the tail is stopped in its downward swing by a tail stop 124 which holds the tail at a detent angle  $\gamma$ , which in turn maintains the turbine at a heading of angle  $\alpha$  from the wind direction.

2. Second embodiment: Figs. 5 and 6:

This second embodiment is similar to the first embodiment except a resilient means such as a spring 128 is be used in lieu of gravity to maintain the tail in position at angle  $\gamma$  during normal operation, and to allow the turbine to furl to the side at excessively high wind speeds. In this case, in strong winds the spring is overpowered by the force of the wind, and the turbine is blown downwind of the yaw bearing, across the wind as in the first embodiment. Also note, in this embodiment the turbine is mounted atop a guyed tower, with the guy wires attached to the tower at a point higher than the lowest reach of the blades. This is an advantage over prior art single-rotor turbines mounted on guyed towers, since in that case the guy wires had to be attached at a point below the rotor blades' reach to avoid being struck by the blades.

3. Third embodiment: Fig. 7:

The third embodiment shows a co-axial, multi-rotor turbine of the present invention mounted directly atop a tripod tower having a very wide stance. No means for aiming the turbine is shown for clarity. The essential feature of this embodiment is to illustrate that

this turbine can be mounted directly upon a wide elevation means such as a tripod due to the inherent large clearance of the rotors from the tower of this design. Prior art turbines could not be so mounted due to limited clearance and the likelihood of a tower strike by a blade.

4. Fourth embodiment: Fig. 8:

The third embodiment shows a co-axial, multi-rotor turbine of the present invention mounted directly atop a building. No means for aiming the turbine is shown for clarity. The essential feature of this embodiment is to illustrate that this turbine can be mounted directly upon a wide elevation means such as a building due to the inherent large clearance of the rotors from the yaw axis of this design. Prior art turbines could not be so mounted due to limited clearance and the likelihood that a blade would strike the building.